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APOLLO 9 SEPARATION AND RECONTACT ANALYSIS SUMMARY DOCUMENT

Flight Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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PROJECT APOLLO

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By Flight Studies Section
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APOLLO 9 SEPARATION AND RECONTACT

ANALYSIS SUMMARY DOCUMENT

By Flight Studies Section

1.0 SUMMARY AND INTRODUCTION

This report is a summary of separation and recontact analyses for the Apollo 9 mission. The purposes of these analyses were to determine the conditions that could produce potential recontact problems and to recommend procedures to alleviate such conditions. All separation and recontact analyses completed to date and applicable to the Apollo 9 mission are summarized, referenced, and indexed in table I.

The nominal mission analyses are summarized in section 3 of this report. The following nominal separations were analyzed for the immediate, close-in, and eventual regions, and no potential recontact problems are present.

1. CSM separation from the S-IVB

2. CSM separation from the four jettisoned SLA panels

3. CSM/LM ejection from the S-IVB (formerly referred to as LM withdrawal)

4. CSM/LM separation (undocking) for rendezvous sequence initiation

5. LM staging

6. LM jettison: the final separation of LM ascent stage from the CSM

7. CM/SM separation for entry

Summaries of separation and recontact analyses of abort conditions are presented in section 4. Potential or possible recontact problems are identified in table I. Descriptions of the recontact regions are as follows.

1. An immediate recontact region exists where there is relative motion between vehicles from the instant of separation until initial clearance is established. Separation clearances involved are usually less than 12 inches; therefore, vehicle dynamics are simulated with 12-degree-of-freedom hybrid or digital computer simulations.

2. A close-in recontact region exists where there is relative motion between vehicles after initial clearance has been established and while the vehicles remain in proximity to each other (i.e., separation range of less than 10 000 ft). Vehicles are simulated by 3-degree-of-freedom digital or analog computer simulations.

3. An eventual recontact region exists where there is a possibility of recontact between two vehicles after sufficient separation ranges have been achieved because of additional vehicle maneuvers, orbital effects, or entry aerodynamics.

2.0 SYMBOLS

APS	ascent propulsion system
CES	control electronics section
CM	command module
COI	contingency orbit insertion
CRO	Carnarvon tracking station
CSI	coelliptic sequence initiation
CSM	command and service modules
DAP	digital auto pilot
DOF	degrees-of-freedom
DRPA	docking ring and probe assembly
EDS	emergency detection system
FAB	Flight Analysis Branch
G&N	guidance and navigation
g.e.t.	ground elapsed time

HAW	Hawaii tracking station
LM	lunar module
RCS	reaction control system
SCS	stabilization and control system
S-IVB	Saturn IVB rocket
SLA	spacecraft/LM adapter
SM	service module
SPS	service propulsion system
T&D	transposition and docking
TPI	terminal phase initiation
T/TCA	thrust and translation control assembly
V_i	inertial velocity
θ	jettison attitude
γ_i	inertial flight-path angle

3.0 SEPARATION AND RECONTACT ANALYSIS OF NOMINAL PROCEDURE

No recontact problems were identified for separations that occurred under nominal conditions. The nominal condition with respect to separation and recontact analysis is defined as separation of stable and controlled vehicles according to mission planning timelines and procedures. The analyses and conclusions of this report are based on compliance with these timelines and procedures prior to and during the actual separation.

3.1 CSM Separation from the S-IVB and the SLA Panels

3.1.1 CSM/S-IVB separation.- Nominal separation of the CSM from the LM/S-IVB is planned at approximately 2^h43^m g.e.t. The spacecraft will separate with a 1-fps ΔV and will begin maneuvers for T&D. These T&D maneuvers and the tables for relative motion during T&D (ref. 1) verify that no recontact problems are present.

3.1.2 CSM/SLA panels separation.- The four spacecraft/SLA panels will be jettisoned at CSM/S-IVB separation. Analysis indicates that no recontact problems are present and that the four panels will deorbit between 3.5 hours and 5.5 hours after jettison (ref. 2). Jettison attitudes of $\theta = 110 \pm 20^\circ$ measured from the S-IVB +X-axis and jettison ΔV's = 11 ± 3 fps were analyzed. Attitude deviations for the S-IVB of $\pm 10^\circ$ in pitch and yaw were considered in the analysis (ref. 2).

3.2 CSM/LM Ejection from the S-IVB

There exists a definite recontact between the CSM/LM and the S-IVB if no evasive maneuvers are performed by the CSM subsequent to ejection (ref. 3). An acceptable evasive maneuver has been determined (ref. 4) which eliminates the possibility of recontact and which places the CSM/LM in a favorable position relative to the S-IVB at S-IVB reignition for ejection opportunities from CRO to HAW.

The recommended CSM gimbal angles at which the RCS evasive burn is to be performed are given in reference 5. [illegible] reference also presents an alternate set of gimbal angles which are satisfactory from the standpoint of recontact. Subsequent to the evasive maneuver, a time history of CSM gimbal angles was generated which would orient the CSM in the proper attitude for the crew to observe the S-IVB visually until the first S-IVB reignition (ref. 6).

Further analyses are presently being conducted to determine whether the maneuver proposed in reference 4 is applicable to ejection opportunities which arise up to one complete revolution after the nominally planned opportunity. Results and recommendations will be published as they become available.

Analysis of the immediate recontact region for the CSM/LM ejection from the S-IVB is presented in reference 7. Results indicate that the LM will not recontact the S-IVB during ejection. Nominal and worst-case separation parameter analysis based on the results of a 12-degree-of-freedom hybrid computer simulation indicates that the LM/CSM can be spring ejected from the S-IVB successfully, unless a spring failure occurs or unless high rates caused by an S-IVB APS failure occurs.

3.3 CSM/LM Separation (Undocking) for Rendezvous Sequence Initiation

The LM-active rendezvous will be initiated by CSM/LM undocking and by a CSM vertically-downward burn of 5 fps which occurs approximately 24 minutes later. The motion of the LM relative to the spacecraft during the entire rendezvous is presented in reference 8, no recontact problems are indicated. Relative motion tables are presented in reference 1.

The phasing burn for the LM (ref. 9) presents no close-in or eventual recontact situations (ref. 10).

A 12-degree-of-freedom hybrid computer simulation was used to determine the CSM and LM separation dynamics which are created by the undocking motion of the probe. The results presented in references 11 and 12 are based on current operational procedures for a nominal CSM/LM undocking maneuver; these results indicate that a CSM/LM undocking presents no immediate recontact problems for the first 15 ft of separation displacement.

3.4 LM Staging During the CSI Maneuver

Nominal staging of the LM is scheduled for the beginning of the CSI maneuver (ref. 8), while the LM is 11 n. mi. above the CSM and 75 n. mi. behind it, and while it is receding from the CSM at a constant rate. Because staging occurs at CSI initiation, the descent stage will remain in the same orbit. Further analyses are being conducted to determine if any eventual recontact situations exist during the next several revolutions. These analyses will be documented as they become available.

The immediate recontact analysis of LM staging (ref. 7) indicates that there are no recontact problems for attitude pitch-roll rates of less than approximately 6 deg/sec. Nominally, the LM will be rate-damped within deadband limits of ±0.1 deg/sec; and staging which will be commanded by the T/TCA, will be performed by the DAP through a four-jet primary translation. This control mode and the four-jet primary translation option agree with that recommended by reference 7 to be used for nominal LM staging when rates have been damped out.

3.5 Final CSM/LM Ascent Stage Separation

The analysis of the final CSM/LM ascent stage separation has been completed (ref. 14). From this analysis, a procedure can be determined by which the LM ascent stage can be separated from the CSM prior to the APS burn to depletion. It is currently planned for the CSM to separate from the LM with the ascent stage alined in its burn-to-depletion attitude. The CSM will then maneuver to and maintain a stationkeeping position directly behind the ascent stage until approximately 10 minutes prior to ascent stage ignition. At this time, the CSM will perform a four-jet SM RCS 3-fps burn which will place the spacecraft above and behind the LM at APS ignition. The immediate recontact analysis of LM jettison from the CSM indicates that there are no recontact problems under nominal conditions and nominal control procedures (CSM SCS, narrow deadband) (ref. 12).

The docking probe and ring are jettisoned with and remain attached to the LM ascent stage at the final CSM/LM separation. Therefore, the preceding analysis is applicable to all areas of possible recontact during this phase of the mission.

3.6 CM/SM Separation

After the SPS deorbit burn cutoff, the crew manually yaws the CSM +X-axis 45° out of plane toward the north, and the SM is separated with a ΔV that is obtained by thrusting the RCS jets for approximately 90 to 100 seconds. The CM/SM separation occurs at 90 seconds after deorbit burn cutoff. Initiation of separation at times greater than 90 seconds after cutoff will decrease the separation ranges between the CM and SM; however, recontact does not occur if separation takes place as late as 5 minutes after the deorbit burn. After separation, the CM will fly a full-lift trajectory to 0.2g, followed by a constant bank-angle trajectory to touchdown.

Based on the nominal entry data defined in reference 1 and on the separation sequence described above, analyses were made of the nominal entry to determine the possibility of recontact between the CM and the SM (ref. 15). Although the SM RCS jets are expected to burn for 90 to 100 seconds, ΔV's of 5 fps, 10 fps, 30 fps, and 65.8 fps were used to verify that separation distances increase as the ΔV increases. The ΔV's correspond to RCS burn times of 6.8 seconds, 13.7 seconds, 41.1 seconds, and 90 seconds, respectively. The SM is expected to have a ballistic trajectory after separation. Constant CM bank angles of 0°, 55° north, and 90° north were used to simulate full-lift entries, G&N entries, and SCS entries, respectively.

No recontacts between the CM and SM were found for the nominal reentry; that is, when the SM is jettisoned south of the orbit plane with a ΔV greater than or equal to 5 fps (ref. 15). Separation as late as 5 minutes after SPS burn cutoff will decrease the separation ranges but will not cause a recontact. Separation is now planned for 5 minutes after the deorbit burn.

Analysis of the CM/SM separation in the immediate recontact region indicates that the interface forces alone are sufficient to preclude recontact. The relative ΔV is 0.94 fps, based on a CM weight of 12 228 lb (ref. 16). Of the interface forces, the ordinance gas pressure impulse is most dominant, the minimum value of which (290 lb/sec) is sufficient to insure no recontact (ref. 17).

4.0 SEPARATION AND RECONTACT ANALYSIS OF ABORT AND ALTERNATE MISSION PROCEDURES

The analyses of the abort regions and alternate missions are considered in six separate phases, based on the vehicles that could be involved in a recontact situation.

1. CSM/S-IVB/SLA panels separation

2. CSM/LM ejection from the S-IVB under nonnominal conditions

3. CSM/LM nonnominal separation

4. Nonnominal LM staging

5. CM/SM separation for entries that result from launch and orbital phase aborts

6. Docking ring and probe assembly jettison from the CSM

4.1 CSM/SLA/Launch Vehicle Separation

This section analyzes launch phase and orbital phase aborts for both stable and nonstable (tumbling) conditions at separation. Included in this section are the following cases.

1. CSM aborts from the S-IVB during the launch phase

2. CSM aborts from the S-IVB, LM/S-IVB, and from the LM during orbit

3. CSM separation from the SLA panels during launch phase and orbital phase aborts

4. CSM/S-IVB separation for aborts initiated under tumbling conditions

5. CSM emergency separation procedure for an impending, detectable explosion of the S-IVB

The following possibilities of recontact were identified.

1. Potential recontact between the CSM and panel 2 for an early mode III abort (item 3 above, section 4.1.3)

2. Under tumbling conditions, possible recontact between the CSM and panels 1 and 2 or the S-IVB after the SPS retrograde mode III abort burn (item 4 above, section 4.1.4.2)

3. Possible recontact between exploding debris and the spacecraft (item 5 above, section 4.1.5)

4.1.1 Stable aborts during the launch phase.- The analysis presented in reference 18 was performed to determine the possibility of recontact between the CSM and the S-IVB for nontumbling aborts initiated during the launch phase (modes II, III, and IV). Criteria for a no-recontact situation are for the separation distance between the CSM and S-IVB to increase monotonically to 100 ft and for this range to be maintained as a minimum approach distance. The results of this analysis confirm that the presently-defined abort procedures for modes II, III, and IV are satisfactory from the standpoint of recontact when initiated from a stable, nontumbling launch vehicle.

4.1.2 Stable aborts from orbit (CSM aborts from the S-IVB, the LM/S-IVB, or the LM).- The analysis documented by reference 19 was performed to determine whether the presently-defined procedures were applicable for orbital aborts initiated while the CSM was attached to the S-IVB or was docked only to the LM. The current procedure for orbital aborts initiated while the CSM is docked to the LM/S-IVB was analyzed in reference 20. Results show that all sequences analyzed are free of recontact problems.

4.1.3 CSM/SLA panels separation, launch phase and orbital phase stable aborts.- The launch phase and orbital phase abort analysis (ref. 2) indicates that the jettison of the four SLA panels at an attitude of $\theta = 110 \pm 20°$ from the S-IVB +X-axis and at a $\Delta V = 11 \pm 3$ fps assures adequate separation displacement from the spacecraft for all abort modes with the exception of the beginning of the SPS retrograde mode III region. If an abort were initiated within the first 30 seconds of the SPS mode III region, a potential recontact situation would exist between the pitched-down panel (panel 2) and the spacecraft.

The mode III abort is not a prime operating procedure and will be required only if it is not possible to use the COI (mode IV abort). Because of this conditional use of the mode III abort and because potential recontact exists for only 30 seconds in the SPS mode III region, the identified potential recontact problems are not considered serious. It is emphasized, however, that the analysis of reference 2 is based on the occurrence of CSM/S-IVB separation and panel jettison under stable (i.e., nontumbling) and controlled conditions. If this were not the case, then relative motions of the SLA panels and of the CSM would be significantly altered, and the conclusions presented in this paper would not necessarily be valid.

The conclusion that no recontact problems are present for orbital phase aborts is based on the analyzed sequences of reference 2 in which the SPS deorbit burn is scheduled for 20 minutes after abort initiation (CSM/S-IVB separation) while the CSM is in the retrograde, heads-up, horizon monitor attitude. Execution of the burn earlier or later or in a different attitude may lead to a potential recontact situation.

4.1.4 <u>Nonstable, tumbling launch phase and orbital phase aborts</u>.-

4.1.4.1 Pre-SPS abort burn: Analysis was performed (ref. 21) to determine whether SPS or RCS rate damping should be used for aborts initiated under tumbling conditions. This analysis is applicable to either the launch phase or the orbital phase of the mission.

Results of the analysis indicate that SPS rate damping can result in recontact between the spacecraft and one of the SLA panels and/or the S-IVB and that RCS rate damping will not result in recontact. Twenty-two to 45 seconds of RCS rate damping under the SCS are required for separation rates of 15 deg/sec to 40 deg/sec, respectively. These times are based on terminating rate damping at 2.5 deg/sec or less. Although the RCS method of rate damping is less efficient, the analysis determined that gimbal lock conditions cannot be prevented by either SPS or RCS rate damping for yaw rates in excess of 10 deg/sec. Based on the results of the analysis, the recommendation is made that RCS/SCS rate damping be used for tumbling aborts.

4.1.4.2 Post-SPS abort burn initiation: Analysis presented in reference 22 determined the potential recontact conditions that could develop after the ignition of the SPS deorbit burn during a mode III or IV tumbling or stable abort. For a tumbling abort, this analysis assumed that RCS rate damping had been successfully completed and that the SPS abort maneuver (deorbit or COI burn) was performed as directed by the mode III or mode IV abort timeline.

Results indicate that, as a consequence of the retrograde SPS burn in the mode III abort region, the CSM will pass within 1000 ft of the S-IVB and/or one of the two in-plane jettisoned SLA panels except for negative pitch rates from 7 deg/sec to 18 deg/sec. Pitch rates of 0 ± 25 deg/sec were analyzed. For the same pitch region, no recontact problems were indicated for the mode IV region. Abort initiation can be delayed for 2 seconds after activation of the EDS abort cue without development of potential recontact.

4.1.5 <u>Emergency separation procedure for an impending, detectable S-IVB explosion</u>.- The planned separation procedure for an impending S-IVB explosion was simulated, and the resultant relative motion is presented in reference 23. The sequence calls for separation of the CSM from the S-IVB with 3 seconds of RCS +X translation followed by 4 seconds of SPS thrust. The resulting relative motion (based on the latest mass data) indicates that the crew could initiate the abort as late as 18 seconds after the warning and could still obtain the 7080-ft separation distance at the time of warning plus 200 seconds.

4.2 CSM/LM Ejection from the S-IVB

Presented in this section are the analyses of CSM/LM ejection under nonnominal conditions, analyses of delay of LM docking and performance of CSM stationkeeping in darkness during T&D, and analyses of an emergency separation procedure for the CSM/LM while it is docked with the S-IVB.

The following areas of potential recontact were identified.

1. The possibility of recontact between the LM and S-IVB exists at ejection for an S-IVB APS failure or for a spring-thrusted failure (section 4.2.1).

2. Recontact between the SC and exploding debris cannot be completely ruled out (section 4.2.3).

4.2.1 Immediate recontact analysis of the CSM/LM ejection from the S-IVB, nonnominal conditions.- The analysis presented in reference 7 determined the conditions that could cause the LM to recontact the S-IVB during ejection (formerly, LM withdrawal). Worst-case separation parameters were combined with single subsystem failures to determine conditions under which recontact would occur.

Results of the analysis indicate that CSM/LM recontact with the S-IVB will not occur under nominal or worst-case separation conditions unless a subsystem failure is involved. Two failure modes which will cause recontact were identified: a single spring thruster failure and a failure of the S-IVB APS. Although CSM RCS jet thrusting is not planned during LM ejection, the failure of an RCS jet was identified as a cause of recontact for ejection performed under CSM SCS control.

Of the systems that were analyzed, the CSM SCS control system with wide deadband and with no pseudorate feedback was considered the best to meet the following three considerations.

1. Avoidance of recontact caused by spring thruster and RCS jet failures

2. Allowance for the largest possible transverse rates which permit CSM/LM ejection without recontact

3. Conservation of the RCS fuel

Operation of the CSM under the control of the SCS with wide deadband limits will permit CSM/LM ejection from the S-IVB under initial transverse rates as great as ±3.6 deg/sec. With this control, RCS jet firings do not occur unless initial rates or a spring failure has occurred; consequently, RCS fuel is conserved.

In consideration of the conclusions, the FAB recommends that LM ejection be performed under CSM SCS control, with the attitude hold in the roll, pitch, and yaw mode with no pseudorate feedback and with maximum deadband (4.0°) and Rate Lo (0.2 deg/sec) switch settings (ref. 24).

4.2.2 CSM/S-IVB stationkeeping in darkness during T&D.- Separation and recontact analyses were performed to recommend a procedure by which the CSM could maintain stationkeeping with the S-IVB in darkness if the crew was unable to dock with the LM/S-IVB during the first daylight pass (ref. 25). The procedure required the crew to maneuver the CSM to a position 100 ft above the S-IVB and then to orient to a specified attitude at the onset of darkness. The +X RCS jets were to be fired for 4 seconds with a subsequent coast through darkness. At daylight, the CSM would be located approximately 1000 ft behind and below the S-IVB.

The procedure described here was developed for a 1968 launch and was not updated for the present launch date because of the crew's desire to perform the stationkeeping manually in darkness.

4.2.3 Emergency separation in the event of an impending S-IVB explosion.- A procedure to separate the CSM/LM from the S-IVB in the event of a detectable, impending S-IVB explosion was analyzed in reference 23. This sequence was designed for the situation in which the CSM is docked with the LM/S-IVB and is unable to jettison the LM quickly.

4.3 CSM/LM Separation

4.3.1 CSM/LM undocking.- Analysis of LM undocking indicates no immediate recontact problems between the probe and drogue for pitch or yaw rates of 0 ± 10 deg/sec (ref. 12). Results indicate that if there is an absence of CSM SCS control during undocking, then greater separation clearances are obtained. These conclusions of no recontact are based on worst-case undocking conditions and on minimum undocking impulses. Recontact during undocking was identified only for jet failures that result in net CSM +X translation.

Based on the results of the analysis of reference 12, recommendations have been made by the FAB that LM undocking be performed without CSM SCS control. Rates should be damped prior to undocking; however, no recontact will occur for rates as high as ±10 deg/sec in yaw and pitch.

4.3.2 LM jettison from the CSM.- Analysis of the immediate recontact region of the pyrotechnic severance of the LM included consideration of pitch-yaw rates (0 ± 10 deg/sec); separation impulses caused by tunnel depressurization (100 to 500 lb/sec); and cases of no control, cases of SCS control and narrow deadband with no jet failures, and cases with jet failures. These three considerations result in no recontact problems with the exception of the case with jet failure, which results in a net +X translation of the CSM. For this situation, -X translation would be required to prevent recontact.

4.4 LM Staging

This section contains analyses of the following.

1. Immediate recontact region

    a. Staging with undamped rates (tumbling)

    b. Staging on alternate missions

2. LM maneuvers during and after staging for alternate missions

3. LM staging for aborts initiated at TPI_0

4. Emergency staging from an unsafe descent stage, docked or undocked

5. Inadvertent staging of the LM

Potential recontact problems were identified for the following.

1. Staging with rates greater than 5 deg/sec to 6 deg/sec (item 1 above, section 4.4.1.1)

2. Possible recontact with exploding debris from the LM descent stage

4.4.1 Immediate recontact region.- Analyses of LM staging that occurs under nonnominal and alternate mission conditions are presented in reference 7. Five control options of the LM DAP and four of the CES were analyzed, and limiting pitch-roll rates were defined for each option under which LM staging could be accomplished without immediate recontact.

4.4.1.1 Tumbling conditions: Results of analyses of staging that occurs under tumbling conditions indicate that LM staging as planned can be accomplished without recontact for rates as high as 5 deg/sec. These analyses also indicate that, for rates higher than 5 deg/sec, recontact can be avoided by a continuous four-jet secondary +X translation with or without LM DAP attitude control (option 2 or 3, ref. 7).

4.4.1.2 Alternate mission conditions: LM staging on alternate missions may occur in either a docked or undocked configuration. Weight variations in the CSM and descent stage during simulation of the actual alternate missions were considered in the analysis of reference 7, the results of which indicate that the LM can be safely staged by the primary LM DAP control mode if undocked, and by either the LM DAP or CSM DAP control mode if docked.

4.4.2 LM maneuvers during and after staging for alternate missions.- With only two exceptions, LM staging during alternate missions can be divided into two categories: staging while the LM is docked with the CSM and staging while the LM is performing stationkeeping with the CSM. The recommended procedure for both stagings is to apply a relative retrograde component of velocity to the descent stage. In the docked configuration, steps to carry out this procedure are to aline the LM +X-axis posigrade, fire the +X translation LM RCS jets for 5 fps, and stage the LM when acceleration is detected (ref. 26).

To stage while in the stationkeeping configurations requires a more complicated procedure. The LM must maneuver to a position down range and behind the CSM, aline its +X-axis posigrade, fire the -X translation jets for 5 fps, then immediately fire the +X translation jets for 5 fps; staging occurs when posigrade acceleration can be detected (ref. 26). In either case, the descent stage falls below and moves ahead of the CSM and ascent stage with no possibility of recontact.

4.4.3 LM staging for aborts initiated at TPI_0.- An analysis was conducted to determine a procedure by which the LM could safely jettison the descent stage for aborts initiated by the LM during the LM-active rendezvous (ref. 27). The TPI_0 maneuver is a four-jet LM RCS +X burn in the retrograde direction to insure a shorter return time to the CSM (ref. 25). Plume impingement during staging imparts a posigrade ΔV to the descent stage which causes it to recede behind the CSM and ascent stage. Prior to staging, the LM performs a 5 fps burn normal to the orbit plane which insures a separation distance between the CSM and descent stage of 4200 ft at the first closest approach. To insure no eventual recontact, the ascent stage is required to dock with the CSM while the docking ΔV has no posigrade components. This requirement can be satisfied by the performance of a small retrograde RCS burn subsequent to docking.

4.4.4 Emergency separation from an unsafe descent stage, docked or undocked.- Because staging from an unsafe descent stage may involve high rates and an emergency situation, staging with a 1-second +X secondary translation (option 2 or 3, ref. 7) is recommended for either a docked or undocked configuration. After staging, analysis indicates that the undocked LM ascent stage can achieve a ΔV = 12 fps and a distance of 60 ft within 10 seconds. If the APS engine is used, the ascent stage can achieve a ΔV = 85 fps and a separation displacement of 350 ft within 10 seconds. If the LM is docked to the CSM, the APS engine will produce a ΔV = 10 fps to 17 fps and a distance of 40 ft to 70 ft (ref. 7).

4.4.5 Inadvertent staging of the LM.- Inadvertent staging of the LM could occur if a staging relay failure occurs while the master arm switch is activated. On the Apollo 9 mission, this could occur just prior to the docked DPS burn and could result in an inadvertent docked staging (CSM/LM ascent from the LM descent stage). Should this occur, analysis indicates that either CSM DAP or LM DAP control during this period is adequate to prevent recontact problems (ref. 7).

4.5 CM/SM Separation

This section contains analyses of CM/SM separations as a result of entries from mode II, mode III, and orbital aborts. No recontact problems were identified between the CM and the SM.

4.5.1 Mode II.- Two possible methods of CM/SM separations were analyzed for the entire mode II abort region (ref. 28). The first method requires that the CSM hold inertially the attitude it had at abort initiation until separation is performed. CM/SM separation at the CM entry attitude is the second method of separation.

No recontacts were found for the first method of separation for small separation ΔV' of 3 fps and 10 fps and for a separation time of 30 seconds after RCS cutoff. The minimum separation distances resulted from an early mode II abort with a separation ΔV of 3 fps. This small a ΔV could result in recontact with the SM debris.

There were no recontact problems associated with separation at the CM entry attitude with ΔV's of 5 and 60 fps and with separation times of 30, 60, and 90 seconds after the RCS burn. The minimum separation distance occurred during an early mode II abort for the 90-second separation time and for a separation ΔV of 5 fps. When the RCS failed to ignite after separation, the separation distances between the CM and the SM were very small for both methods, and the possibility existed of CM recontact with SM debris.

No actual recontacts were discovered for either type of separation. The greater the time of free fall is from separation to entry interface and the larger the separation ΔV, the greater the separation range is between the CM and the SM. Although there is the possibility of recontact with the SM debris for early mode II aborts if the SM ΔV is less than 3 fps, the probability of achieving a ΔV this small is very remote.

4.5.2 Mode III.- Separation times of 10, 30, and 60 seconds after SPS burn cutoff (or RCS burn cutoff for early mode III aborts) as well as SM in-plane separation ΔV's of 3 and 7 fps were evaluated in reference 29 to determine the effect of time of free fall and separation ΔV on separation distances between the CM and the SM. The minimum separation distance occurred for a late mode III abort where the SM was separated in plane with a ΔV of 3 fps 60 seconds after SPS cutoff. There was no problem of recontact for this separation ΔV and for this time of free fall. Separation distances increased as the time of free fall from separation and the separation ΔV increased.

4.5.3 Deorbits prior to nominal deorbit.- There is the possibility that the mission might have to be terminated early. The separation and recontact analysis performed for the nominal entry is not applicable for entry earlier in the mission because the weight of the SM is significantly different. The CM/SM separation and recontact analysis for these deorbits during the mission is presented in reference 30. A ballistic SM trajectory 45° out of plane and with a ΔV of 5 fps, was used in all cases after a separation. The CM flies full-lift to 0.2g and then flies a constant bank angle to touchdown. Bank angles of 0° (full-lift entry), 55° north (G&N entry), and 90° north (SCS entry) were simulated in the study.

No recontacts between the CM and the SM were discovered for deorbits that occurred at any time during the mission. The minimum separation distance resulted from a high-speed entry (V_i = 27 000 fps, γ_i = -2.93°) for deorbits after the third, fourth, and fifth SPS burns in which the ballistic coefficient ratio of the CM to the SM was between 0.9 and 1.0. The minimum separation distance was 2840 ft, which corresponded to a separation ΔV of 5 fps and to a full-lift CM trajectory. The expected SM RCS burn time of 90 to 100 seconds and CM bank modulation after 0.2g will increase the separation distances greatly.

4.6 Docking Ring and Probe Assembly Jettison For Launch and Orbit Phase Aborts

This section presents results of an analysis to determine if the jettison of the DRPA at CM/SM separation will create any potential recontact problems for mode II, mode III, and orbital aborts. The existence of a potential recontact problem with the CM during a mode II abort is dependent upon the jettison attitude of the DRPA.

4.6.1 Mode II.- During the nominal mission, the DRPA will remain with the LM ascent stage after final separation from the CSM. If a mode II abort should occur, the DRPA, which is still attached to the CSM, would have to be separated prior to entry because its presence during entry could interfere with the chute deployment and flotation bags used to upright the CM from the stable II position.

The analysis presented in reference 31 indicates that there is a problem of recontact between the DRPA and CSM if the DRPA is jettisoned with a ΔV of 6 fps at approximately the same attitude as the booster at the time of abort. The early mode II abort case was found to be the most critical. When the DRPA is jettisoned at the same attitude as the booster at the time of abort for times of 4 seconds, 30 seconds, and 60 seconds after RCS burn termination, the DRPA flies in front of and above the CM until the CM is between the attitudes of 200 000 and 100 000 ft. While the DRPA is within this altitude range, it drops below and behind the CM because of the lifting trajectory of the CM. Minimum separation distances for the separation times of 4 seconds, 30 seconds, and 60 seconds were 165 ft, 140 ft, and 145 ft, respectively. Separation distances for later mode II aborts were somewhat larger; however, because of unknowns in the atmosphere and because of DRPA aerodynamics, recontact for the latter mode II cases could also occur for these abort cases. Jettison of the DRPA at CM entry attitude resulted in the positioning of the CM safely in front of the DRPA for the considered times of separation.

4.6.2 Mode III.- The DRPA separation from the CM was analyzed in reference 31 for the case of in-plane separation of the DRPA at the deorbit attitude. Separation occurred at the same time as CM/SM separation. The DRPA separation range converged slightly for an early mode III abort, while for a late abort, the separation distances increased monotonically. No recontacts were discovered for the entire abort phase.

4.6.3 Orbital abort.- In-plane and out-of-plane jettison attitudes were examined in reference 31 for recontact possibilities after an orbital abort. Separation was performed at the same time as CM/SM separation and at the deorbit attitude. Separation ranges for both in-plane and out-of-plane jettisons are more than sufficient to preclude recontact.

TABLE I.- SUMMARY OF SEPARATION AND RECONTACT ANALYSIS

(a) Nominal mission

Separation	Document section	Reference
CSM/S-IVB separation	3.1.1	1
CSM/SLA panels separation	3.1.2	2
CSM/LM ejection from S-IVB (LM withdrawal)	3.2	3, 4, 5, 6, 7
CSM/LM separation (undocking)	3.3	1, 8, 9, 10, 11, 12
LM staging	3.4	8, 13
Final CSM/LM separation (LM jettison)	3.5	12, 14
CM/SM separation	3.6	1, 15, 16, 17

(b) Aborts and alternate missions

Separation	Recontact problems	Document section	Reference	Comments
CSM/S-IVB separation	No	4.1.1	18	Stable aborts, launch phase
CSM/LM/S-IVB separations	No	4.1.2	19, 20	Stable aborts, orbit phase
CSM/SLA panels separation	Yes	4.1.3	2	Stable aborts, mode III
CSM/S-IVB/SLA panels separation	Yes	4.1.4	21, 22	Tumbling aborts, mode III

TABLE I.- SUMMARY OF SEPARATION AND RECONTACT ANALYSIS - Continued

(b) Aborts and alternate missions - Continued

Separation	Recontact problems	Document section	Reference	Comments
CSM separation from an impending S-IVB explosion	No	4.1.5	23	Procedure recommended; cannot eliminate possibility of recontact with debris
CSM/LM ejection from S-IVB	Yes	4.2.1	7	Failed spring thruster, high transverse rates; procedure recommended to avoid recontact
Extended CSM stationkeeping with S-IVB	No	4.2.2	25	Procedure recommended
CSM/LM separation from an impending S-IVB explosion	No	4.2.3	23	Procedure recommended: cannot eliminate possibility of recontact with debris
CSM/LM separation (undocking)	No	4.3.1	12	
LM jettison from the CSM	Yes	4.3.2	12	Only for jet failures that result in a +X translation of the CSM
LM staging with tumbling rates	No	4.4.1.1	13	Necessary to follow recommended procedure
LM staging, stable alternate missions	No	4.4.1.2	13	Analyses made of alternate mission weights and configurations

TABLE I.- SUMMARY OF SEPARATION AND RECONTACT ANALYSIS - Concluded

(b) Aborts and alternate missions - Concluded

Separation	Recontact problems	Document section	Reference	Comments
LM maneuvers during and after staging for alternate mission	No	4.4.2	26	Procedures recommended
LM staging for aborts at TPI_0	No	4.4.3	9, 27	Procedures recommended
Emergency separation from an unsafe descent stage	No	4.4.4	13	Procedure recommended, cannot eliminate possibility of recontact with debris
Inadvertent staging	No	4.4.5	13	Control mode recommended
CM/SM separation	No	4.5	28, 29, 30	Mode II, III, orbital abort entries analyzed; cannot eliminate possibility of recontact with SM debris for an SM RCS failure after CM/SM separation for early mode II aborts
Docking ring and probe jettison	Yes	4.6	31	Procedure recommended to avoid recontact in mode II aborts

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